FINAL PROJECT – ME 141502

DESIGN EXPERIMENT FOR ANALYZING THE USE OF AIR LUBRICATION SYSTEM TO REDUCE FRICTIONAL RESISTANCE ON SHIP HULL

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Surabaya
2016

SKRIPSI– ME 141502

DESAIN EKSPERIMEN UNTUK MENGANALISA PENGGUNAAN AIR LUBRICATION SYSTEM UNTUK MENGURANGI TAHANAN GESEK PADA BADAN KAPAL

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APPROVAL SHEET

DESIGN EXPERIMENT FOR ANALYZING THE USE OF AIR LUBRICATION SYSTEM TO REDUCE FRICTIONAL RESISTANCE ON SHIP HULL

BACHELOR THESIS

Proposed to Meet One of Terms
Obtaining a Bachelor of Engineering
On
Marine Machinery and System Laboratory(MMS)
Program of Bachelor Degree Marine Engineering
Faculty of Marine Technology
Institut Teknologi Sepuluh Nopember

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JULI 2016

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BACHELOR THESIS

Submitted to Comply One of The Requirements to Obtain a Bachelor Engineering Degree
on
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Faculty of Marine Technology
Institut Teknologi Sepuluh Nopember

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DESIGN EXPERIMENT FOR ANALYZING THE USE OF AIR LUBRICATION SYSTEM TO REDUCE FRICTIONAL RESISTANCE ON SHIP HULL

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Student Number : 4212101035
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ABSTRACT

In this study, simple experiment will be conducted by making and executing the implementation from experiment to determine the effect of air lubrication for reduces frictional resistance on the hull. Frictional resistance is one of major influences on determine needs of power to propel vessel. This friction occurs because there are two media rubbing on each other that are hull and water. Air Lubrication System is an additional system used to reduce frictional resistance by injecting air to the bottom of the hull; this is done to reduce the friction between the ship hulls with water. Towing tests conducted on a model ship that not using ALS and models of ships using ALS. Model Speed when given weight 0.4 kg, when not using ALS the speed was 0.518 m/s, compare to speed when using the model of ALS was 0.538 m/s. From calculation results, can be obtained resistance value at a speed of 1.3 knots, ship resistance without the use of ALS is 62650,635 N, while the ship resistance when using ALS is 56272,822 N.

Keyword: ***Air Lubrication, Ship Resistance, Towing Test***

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DESAIN EKSPERIMEN UNTUK MENGANALISA PENGGUNAAN AIR LUBRICATION SYSTEM UNTUK MENGURANGI TAHANAN GESEK PADA BADAN KAPAL

Nama Mahasiswa	: Irsyadul Afif Rz
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Dosen Pembimbing 2	: Ir. Dwi Priyanta M.SE

ABSTRAK

Dalam penelitian kali ini, akan dilakukan pembuatan dan pelaksaan eksperiment sederhana untuk mendapatkan dan mengetahui pengaruh dari lubrikasi udara dalam mengurangi tahanan gesek pada badan kapal. Tahanan gesek merupakan salah satu pengaruh terhadap kebutuhan daya untuk mendorong kapal. Gesekan terjadi karena ada dua media yaitu badan kapal dan air yang saling bergesekan. *Air Lubrication System* merupakan system tambahan yang digunakan untuk mengurangi tahanan gesek dengan menginjeksikan udara bertekanan ke bawah badan kapal, hal ini dilakukan untuk mengurangi gesekan antara badan kapal dengan air. Uji tarik dilakukan menggunakan model kapal yang salah satunya tidak menggunakan ALS dan model kapal yang menggunakan ALS. Kecepatan Model pada berat 0.4 kg saat tidak menggunakan ALS adalah 0.518 m/s, sedangkan kecepatan saat model menggunakan ALS adalah 0.538 m/s. Dari hasil perhitungan didapatkan pada kecepatan 1.3 Knot, tahanan kapal tanpa menggunakan ALS adalah 62650.635 N, sedangkan tahanan kapal pada saat menggunakan ALS adalah 56272.822 N.

Kata Kunci: ***Lubrikasi udara, tahanan kapal, uji tarik***

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Alhamdulillahirabbil ‘alamin, Praise merely to the Almighty Allah SWT for his gracious mercy and tremendous blessing that enables author to accomplish this bachelor thesis entitled: “***Design Experiment for Analyzing the Use of Air Lubrication System to Reduce Frictional Resistance on Ship Hull”***. This bachelor thesis is presented to fulfill one of the requirements in accomplishing S-1 Double Degree in Marine Engineering Study Program, HS-Wismar Germany and Institut Teknologi Sepuluh Nopember, Surabaya. I would like to express my special appreciation to my advisers Taufik Fajar Nugroho, S.T., M.Sc. and Ir. Dwi Priyanta, M.SE. Author wants to say thank you for their valuable knowledge and inspiration to author when completing this bachelor thesis report. The author realized in this thesis is far from perfect, therefore the authors expect criticism and constructive suggestions towards better that enhance existing knowledge in this thesis. The author also delivers apologize if during the process of this thesis there are some mistakes. During the process of this paper the author gets a lot of support and assistance directly or indirectly from the various parties, so that on this occasion the author would like to thank to:

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The authors fully recognize that this bachelor thesis is still far from perfection, criticisms and suggestions that can help author to become a better writer are always expect from the readers. Finally, the author hopes that what has been written in this paper could be useful for common reader and writer in particularly.

Surabaya, July 2016

AUTHOR

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CHAPTER I:
INTRODUCTION

1.1 BACKGROUND

Drag resistance is an important factor when it comes to power needed by engine to propel a ship. Reducing drag resistance means reducing power and so reduction of fuel consumption, which leads to higher profit margins and a cleaner environment.

Fluid frictional drag accounts for as much as 60- 70% of the total drag for cargo ship, and about 80% of that for a tanker. The drag reduction by micro-bubbles is able to achieve a drag reduction rate as high as 80%. Relatively small reduction of the total drag can result in a substantial fuel saving.

Developing energy-saving ships has been greatly anticipated by the shipping industry as a countermeasure against the increasing prices of raw materials, including oil, arising from the economic growth of developing countries, and environmental issues about CO_2 emission regulations for international shipping operations. The air lubrication method used to reduce drag resistance from the hull by using air bubbles, has been studied by a number of institutes because the method is expected to result in giving effect for energy-saving.

1.2 PROBLEMS STATEMENT

Existence of frictional force on the hull causing the power needed to propel the ship to be increase than if there is no friction on the hull. This frictional force exists because there are two Medias that rub to each other. To minimize the pulling force to propel the ship, the friction force must be

eliminated. However, the friction force cannot be eliminated. The frictional force can only be minimized.
Friction can be reduced by 3 ways, as follows:

a. Smoothed the wetted surface area, can be done by sanding or give oil on the surface.
b. Giving the wheels on the areas of come in contact is one effort to smoothed area surfaces that come into contact so that the friction force can be minimized. However, this method is mainly aimed to take advantage of the motion "rolling" to avoid rubbing motion.
c. Separating the two surfaces in contact with air. This principle is already applied to the hovercraft. This ship can move easily (friction is small enough) because of the air pressure to the top that can lift the hull. The presence of “air cushion" minimizes friction from the ground with water. This means the ship can hover in swamp areas, deep snow, or water without sinking. Air cushion lifting the boat out of the soil surface is produced by a large fan.

Based on the description above, there is several formulation of the problem, namely:

a) Analyze placement of Air Lubrication System outlet for discharging bubble layers.
b) Analyze the bubble layer flow generated by the system.
c) Analyze how much frictional reduction can be obtained.

1.3 SCOPE OF PROBLEMS

Scope of problems for this experiment is:

1. Placement of Air Lubrication System outlet for discharging bubble layers.
2. How to generate bubble on ship model?
3. How to measure resistance?

1.4 PROBLEM LIMITATIONS

Problem limitation for this bachelor thesis is:

1. The study is done by doing experiment.
2. Experiments are done at Workshop of Marine Machinery and System Laboratory

1.5 EXPERIMENT OBJECTIVE

This Bachelor Thesis aims to:

- Design Experiment for Air Lubrication System.
- Understand how to prepare experiment for Air Lubrication System.
- Understand the influence of Air Lubrication System on reducing ship resistance.

1.6 EXPERIMENT BENEFITS

Benefits to be gained from this thesis are:

1. Understand how to prepare experiment
2. Give a better knowledge about how to reduce the drag resistance on the vessel.
3. Understanding the system of Air Lubrication working principal.

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CHAPTER II:
LITERATURE STUDY

2.1 PREVIOUS EXPERIMENT

The air bubble distribution on the hull surface of a ship with the Mitsubishi Air Lubrication System (MALS) and the amount of air bubbles flowing into the propeller were roughly predicted using a model-scale analysis. The results confirmed that the air bubble distribution on the ship bottom surface varied little in response to changes in the air bubble diameter. (Kawabuchi M, et al 2011)

The changes in the bubble diameter did not affect the peak position of the void fraction on the propeller disk area, while the void fraction of air bubbles flowing into the propeller increased as the air bubble diameter decreased. (Kawabuchi M, et al 2011)

Bubble size is one of the major factors influencing frictional resistance. Bubbles of a few millimeters in diameter can increase the frictional resistance. It is happened possibly because the turbulence generated in bubble wake. When micro-bubbles are ejected pass through hole or porous plate, the bubble size is decided by the main flow velocity and the air flow rate, and not by the size of the hole (Hashim, A., et al 2015).

Microbubble injection location is one of the important parameters that need to be considered in reviewing the effectiveness of skin friction reduction by micro bubbles. Experiment on high speed vessel model to test the efficiency of micro bubbles on resistance reduction. The micro bubble injector position is showed in Figure 4. The results showed that the location of micro bubbles injection behind the midship (position 3) is the best location to achieve the most effective drag reduction and has caused about 6-9% of drag reduction. In figure below is the description of injection position made by them. Position 1 is at front of midship, position 2 at midship and position 3 at aft of midship (Hashim, A., et al 2015).

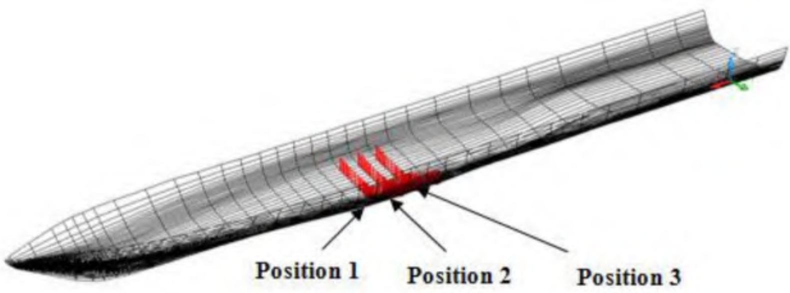

Figure 2-1. Lines Plan and Microbubble Injector Position

(Hashim, A., Yaakob, K., Ismail, N., & Ahmed, Y. (2015). Review of Micro-bubble Ship Resistance Reduction Methods and the Mechanisms that Affect the Skin Friction on Drag Reduction from 1999 to 2015. *Jurnal Teknologi (Sciences & Engineering)*, 105-114)

The location of micro-bubbles injection behind the mid-ship section is the best location to get effective drag reduction. Extensive experiments on microbubble filled turbulent boundary layer and found that the bubbles were more effective when ejected from a plate on top than from a plate on bottom. A possible explanation of the phenomenon is the reduction of turbulence intensity caused by microbubbles which increase the effective viscosity of the water-bubble mixture (Hashim, A., et al 2015).

Apply an air lubrication method to a large shallow-draft twin-screw carrier, we carried out a mock-up test and air blow-off condition test on a wharf wall in advance and were able to confirm a net energy-saving effect of a maximum of 12 percent in a sea trial through the use of an actual carrier. The skin friction resistance of the carrier decreased through the use of an air lubrication method, which is thought to act to decrease the load of the propeller. (Mizokami, S., et al 2010)

2.2 THEORY

Air Lubrication System is a method to reduce the resistance between the ship's hulls with seawater using air bubbles layer. The working principle of the Air Lubrication System is by trapping a layer of air bubbles under the hull. Some air blower or similar tool made to create air bubbles that continuously past the bottom surface of the vessel. Place out air bubbles created in several different locations throughout the lower part of the stomach, symmetrically on either side of the centerline of the ship.

The air is removed in size and a constant speed to create a layer of air bubbles, which can reduce the resistance between the ships with sea water. Ongoing basis the system will displace air bubbles that have disappeared to ensure that the layer is flat and constant can be maintained under the hull so that the expected results can occur.

Methods to reduce drag with air lubricating system can be done in three ways:

a. Creating a thin layer of air under the surface of the ship.
   A layer of tiny air bubbles produced at the front of the boat and must be directed so that it can flow under the ship. This method can reduce the drag Resistance. Some experiments have been done with a model ship and prove this method can reduce the ship resistance by up to 20%. These experiments need to consider several things, one of which influences the diameter of the bubble. For this method should be added certain equipment and some modifications to create air pressure to compose and maintain a layer of air bubbles.

b. Creating a compartment beneath the ship is filled with air. Compartment made under the ship and will be filled with constant air flow. This method will reduce the surface area of the vessel in contact with water (wetted surface). This can reduce the drag resistance. This method is called "Air Cavity Chamber Lubrication”. Air lubrication system used for this type of vessel that has a large surface area and a flat bottom. This is due to the large surface area and a flat bottom that can be made compartments to place the air cavitation.

c. Create a thin layer of air with waterproof paint. The third method is actually not using air lubrication. As mentioned previously, the boundary layer of air is formed from water rubbing around the ship. The goal of this method is to prevent the boundary layer to be formed. This method can be used as an additional feature for the two previous methods.

While to produce air bubbles can be used several methods, namely, Electrolysis Method, Porous Methods, and Venturi Tube Bubble Generator Method. The number and size of the bubbles can be adjusted via the method to be used. The following description:

a) Electrolysis
Electrolysis is a method to produce air bubbles on the surface of the metal wire by means of a current or a high voltage through it. When an electric current source connected to two electrodes submerged in water, the hydrogen will be produced at the cathode and oxygen will be generated at the anode. Used for cathode copper wire coil, while acting as the anode is bilge.

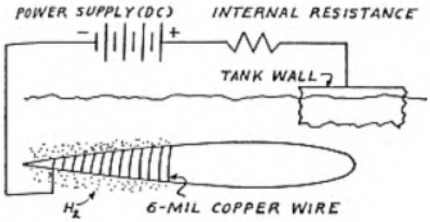

Figure 2-2. Schematic Diagram of Hydrogen Microbubbles Experiment
(Hashim, A., Yaakob, K., Ismail, N., & Ahmed, Y. (2015). Review of Micro-Bubble Ship Resistance Reduction Methods and the Mechanisms that Affect the Skin Friction on Drag Reduction from 1999 to 2015. Jurnal Teknologi (Sciences & Engineering), 105-114)

b) Porous Method Bubble Generator
   Porous method is the simplest method and the most popular for use in research. Using this method, the air bubbles are generated by inserting a pressurized air through a porous medium. There are several types of porous medium to produce air bubbles.

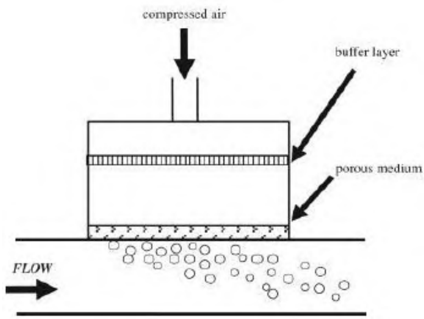

Figure 2-3. Schematic Drawing of the Microbubbles Generation Through Porous Medium
(Hashim, A., Yaakob, K., Ismail, N., & Ahmed, Y. (2015). Review of Micro-Bubble Ship Resistance Reduction Methods and the Mechanisms that Affect the Skin Friction on Drag Reduction from 1999 to 2015. Jurnal Teknologi (Sciences & Engineering), 105-114)

c) Venturi Tube Type Bubble Generator
   Venturi tube is a tube with a certain construction that drains the fluid along pipes with varying diameters. Due to the difference in pressure inside the tube, forming air

bubbles. To produce it, the air is first injected at the upstream side of the nozzle. Along with a mixture of water and air are mixed passes through the nozzle, which has a minimum pressure, the more air bubbles are formed. Recovery stress on other parts of the nozzle will cause air bubbles then burst into a smaller size.

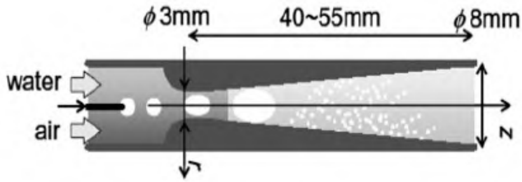

Figure 2-4. Schematic Sketch of the Venturi Tube Type Bubble Generator
(Hashim, A., Yaakob, K., Ismail, N., & Ahmed, Y. (2015). Review of Micro-Bubble Ship Resistance Reduction Methods and the Mechanisms that Affect the Skin Friction on Drag Reduction from 1999 to 2015. Jurnal Teknologi (Sciences & Engineering), 105-114)

The reduction of frictional drag depends on the wetted surface area of a ship and the fluid flow around it. However, it is quite difficult to change the wetted surface area. Thus, a mechanism to vary the viscosity of the boundary layer around the ship has to be figured out. There are some important basic parameters that would give an optimum impact to generate micro-bubble. (Hashim A, et al 2015)

2.2.1 Gravitational Towing

Model towed by the falling weights. First set of the models and weights position where there was no movement to the model. Then, add the first weight, where mass is small enough to mobilization / towed models. The greater the mass for the weight, the higher the speed produce. It is synonymous with squared speed value to resistance. There are at least five different weights, each weight provides a certain mass or gravity. Speed is measured by towed together the mass of each weight from the run. Results are expressed in the form of a graph where the horizontal axis is speed the vertical axis is resistance.

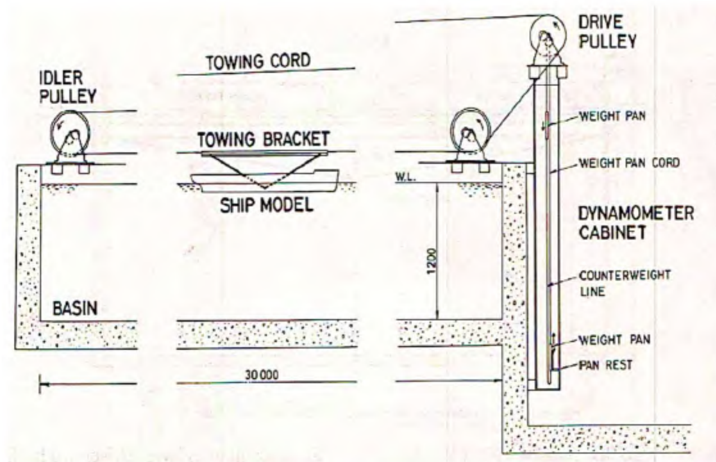

Figure 2-5 "Wellenkamp System" Towing Tank
(Harvald, S. A. (1983). *Resistance and Propulsion of Ship.* Lyngby: John Wiley & Sons. Inc.)

2.2.2 Ship-Model Correlation

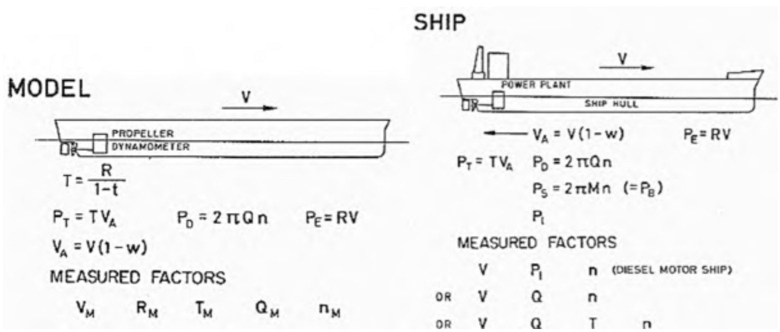

Figure 2-6. Model-Ship Correlation
(Harvald, S. A. (1983). *Resistance and Propulsion of Ship.* Lyngby: John Wiley & Sons. Inc.)

For determining the ship speed from model speed, the similarity laws to be comply by:

1. Geometrics Similarity
   Geometric similarity is very difficult to be met considering the ships voyage at sea, sea levels are considered infinitely wide and nearly infinite depth while the pool size is limited by the size of the ship model should be small, comparable to the size of the pool or other.

   Similarly, the surface pressure on the tank experiments considered the same as atmospheric pressure, where the pressure supposed to be reduced. Geometrical conditions can be fulfilled in an experimental model but only models linear dimension.

   Relationship between model and ship is expressed by λ, where;

   $$\lambda = \frac{L_s}{L_m} \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2.3.1)$$

   Where:
   - λ = Scale Ratio
   - L_s = Ship Length (m)
   - L_m = Model Length (m)

2. Kinematic Similarity
   Kinematic similarity between model and ship are corresponding with the model speed to the ship speed. Kinematic similarity between the model and

ships more focused on the relationship between the speeds of the model with the actual boat speed.

With the scale ratio that shows the relationship between speed and velocity model of the actual ship it can be said that the kinematic similarity can be met.

$$Fr = \frac{V}{\sqrt{g\,L}} \quad \text{.................. (2.3.2)}$$

Or

$$\frac{V_s}{\sqrt{g\,L_s}} = \frac{V_m}{\sqrt{g\,L_m}} \quad \text{.............. (2.3.3)}$$

Where:

Fr	= Froude Number
L_s	= Ship Length (m)
L_m	= Model Length (m)
V_s	= Ship Speed (m/s)
V_m	= Model Speed (m/s)
g	= Gravitation (9.81 m/s^2)

3. Dynamic Similarity

Dynamic similarity relates to forces that happen by the movement of fluid around the model. Forces works with respect to fluid movement around the model and ships at any point or place of the corresponding must have the same magnitude and direction, in this case the Reynolds Number Value depicting style comparing inertia with viscosity

$$Rn = \frac{V\,L}{\nu} \quad \text{.................. (2.3.4)}$$

Or

$$\frac{V_s\,L_s}{\nu} = \frac{V_m\,L_m}{\nu} \ldots\ldots\ldots\ldots\ldots \text{(2.3.5)}$$

Where:

Rn	= Reynolds Number
L_s	= Ship Length (m)
L_m	= Model Length (m)
V_s	= Ship Speed (m/s)
V_m	= Model Speed (m/s)
ν	= Kinematic Fluids Viscosity (m^2/s)
ν	= 1.1883×10^{-6} (m^2/s)

2.2.3 Ship Resistance

The resistance of a ship at a given speed is the force required to tow the ship at that speed in smooth water, assuming no interference from the towing ship. The total calm water resistance as being made up of four main components:

a) Frictional resistance,
   This is the motion of the hull when it through a viscous fluid.
b) Wave making resistance
   Energy that must be supplied continuously by the ship to the wave system created on the free surface.
c) Eddy resistance
   Energy carried away by eddy current shed from the hull or appendages. This is especially severe at the stern where the water may be unable to follow the curvature and will break away from the hull, giving rise to eddy current and separation resistance.

d) Air resistance
This is experienced above water part of the main hull and the superstructures due to the motion of the ship through the air.

Frictional resistance coefficient (C_F), using ITTC formula:

$$C_F = \frac{0.075}{(\log Re \quad)^2} \text{.............. (2.3.6)}$$

Where:

C_F = Frictional Resistance Coefficient
Re = Reynolds Number

Frictional Resistance (R_F), equation:

$$R_F = \frac{\rho \, S \, V^2 \, C_F}{2} \text{................ (2.3.7)}$$

Where:

R_F = Frictional Resistance
ρ = Density
S = Wetted Surface Area
V = Ship Speed
C_F = Frictional Resistance Coefficient

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CHAPTER III: METHODELOGY

In order to solve the problem above, that will be used data analysis from conducting experiment. This can be seen in the flowchart at Figure 3-1. There are several stages:

3.1 LITERATURE STUDY

The study of literature is an early stage is the stage of learning about the basic theories to be discussed or used in the thesis. First of all is finding the basic theory of the Air Lubrication System, the best position to place Air lubrication system on ship model, parameters to get for calculating the ship resistance. Sources taken at this stage comes from books, papers, websites and journals.

3.2 PREPARING EXPERIMENT

This phase is to prepare the experiment by collecting and configure the material so it ready to be use for experiment. In this experiment, equipment that needs to be prepared is:

a) Ship Model
Ship model is prepared to be able to install water injection lubrication system. This is can be achieve by making holes under ship bottom to make ways for bubble discharge.

b) Bubble Generator
Bubbles are produce from using compressor to generate pressurize air. When the pressure air is discharge, it will produce bubbles where it can cover bottom of the ship.

c) Gravitational Towing Mechanism
To achieve resistance value, gravitational towing is use. This towing method use gravity to determine force value.

Force value will represent as resistance of ship, where the masses are got from using weight. The masses variants at 200 grams, 400 grams, 600 grams, 800 grams, and 1000 grams. Speed of the ship can be obtained by measuring time from point A to point B, and then the length and time will show the velocity result.

3.3 EXPERIMENT

Experiment conduct to obtain data about the use of bubble layer in the bottom of the ship that will be use in data analysis. This study was designed to test the pull in the flow channel. With 2 conditions for the object, that are first condition for ship models tested without using Air Lubrication System and the second testing is using Air Lubrication System on the ship model.

1) Experiment without using Air Lubrication System
   Steps for doing the experiment are:
   a) Ship model are place inside flow channel.
   b) Prepare the model to be pull with hook.
   c) Adding weight with 100 grams, 200 grams, 300 grams, 400 grams, 500 grams.
   d) Measure time need by the model need to cross 1.2 meters long flow channel after the model were pull for about 50cm - 100m

2) Experiment using Air Lubrication System
   Steps for doing the experiment are:
   1. Ship model are place inside flow channel.
   2. Prepare the model to be pull with hook.
   3. Starting the compressor and adjust pressure output at 2 bar.

4. Adding weight with 100 grams, 200 grams, 300 grams, 400 grams, 500 grams.
5. Measure time need by the model need to cross 1.2 meters long flow channel after the model were pull for about 50-100 cm

Experiment performed without any currents and waves. Experiments are done with the same model thus distinguishing factor only the use of Air Lubrication System. Bubble generator is set with the same pressure during the experiment. Same Pressure ensuring the flow rate is unchanged so the bubble generator not causing any other influence to ship resistance.

3.4 DATA ANALYSIS

Data analysis is the stage where the scientific analysis is done. It is aimed to find out how air lubrication system can lead to friction reduction. From the experiments conducted, the data obtained for the resistance from both experiment. With data from the resistance will be able to analyze the influence of air lubrication system to ship resistance from comparison the two experiments.

Variables for this experiment are:

- Mass (M)
- Distance from Point A to Point B.
- Output pressure from compressor.

Data will be collect from experiment:

- Time from point A to point B.

Data that will be calculated are:

- Force (F)
- Velocity of the ship model.

The procedure to calculate resistance is:

1) Test the model with Fn number scaling,

$$V_m = V_s/\sqrt{\lambda} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.4.1)}$$

Where;

$$\lambda = L_s/L_m \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.4.2)}$$

Where:

λ	= Scale Ratio
V_m	= Model Speed (m/s)
V_s	= Ship Speed (m/s)
L_s	= Ship Length (m)
L_m	= Model Length (m)

2) Measure the total resistance $(R_T)_m$
Estimate the frictional resistance of the model $(R_F)_m$ by using flat plate results at the model's Reynolds number.

3) Compute the model residuary resistance from

$$(R_r)_m = (R_T)_m - (R_F)_m \ldots\ldots\ldots\ldots \text{(3.4.3)}$$

Where:

$(R_r)_m$	= Model Residual Resistance (N)
$(R_T)_m$	= Model Total Resistance (N)
$(R_F)_m$	= Model Frictional Resistance (N)

4) Since $(C_r)_s = (C_r)_m$, we can find the ship residuary resistance

$$(R_r)_s = 1/2\, (C_r)_s\, \rho\, V_s^2\, S_s \ldots\ldots\ldots \text{(3.4.4)}$$

Or

$$(R_r)_s = 2\, (C_r)_m\, \rho\, V_m^2\, S_m\, \lambda^3 \ldots\ldots \text{(3.4.5)}$$

Where:

$(R_r)_s$ = Ship Residual Resistance (N)
$(C_r)_s$ = Coefficient Ship Residual Resistance
$(C_r)_m$ = Coefficient Model Residual Resistance
ρ = Density Coefficient (kg/m^3)
V_s = Ship Speed (m/s)
V_m = Model Speed (m/s)
S_s = Ship Area (m^2)
S_m = Model Area (m^2)
λ = Scale Ratio

5) Estimate the frictional resistance of the ship (RF)s by using flat plate results at the ship's Reynolds number.

6) Compute the total ship resistance by

$$(R_T)_s = (R_r)_s + (R_F)_s \ldots\ldots\ldots\ldots\ldots \quad (3.4.6)$$

Where:

$(R_T)_s$ = Ship Total Resistance (N)
$(R_r)_s$ = Ship Residual Resistance (N)
$(R_F)_s$ = Ship Frictional Resistance (N)

3.5 CONCLUSION & REPORTING

Make conclusions based on the results obtained and suggestions for further research development. Research data for ship resistance obtained after the towing test. Data between two towing test and then compare the two obtained data using the speed-resistance chart. From comparison of the data, the authors can draw conclusions about the impact or influence of Air Lubrication System to arrest the ship.

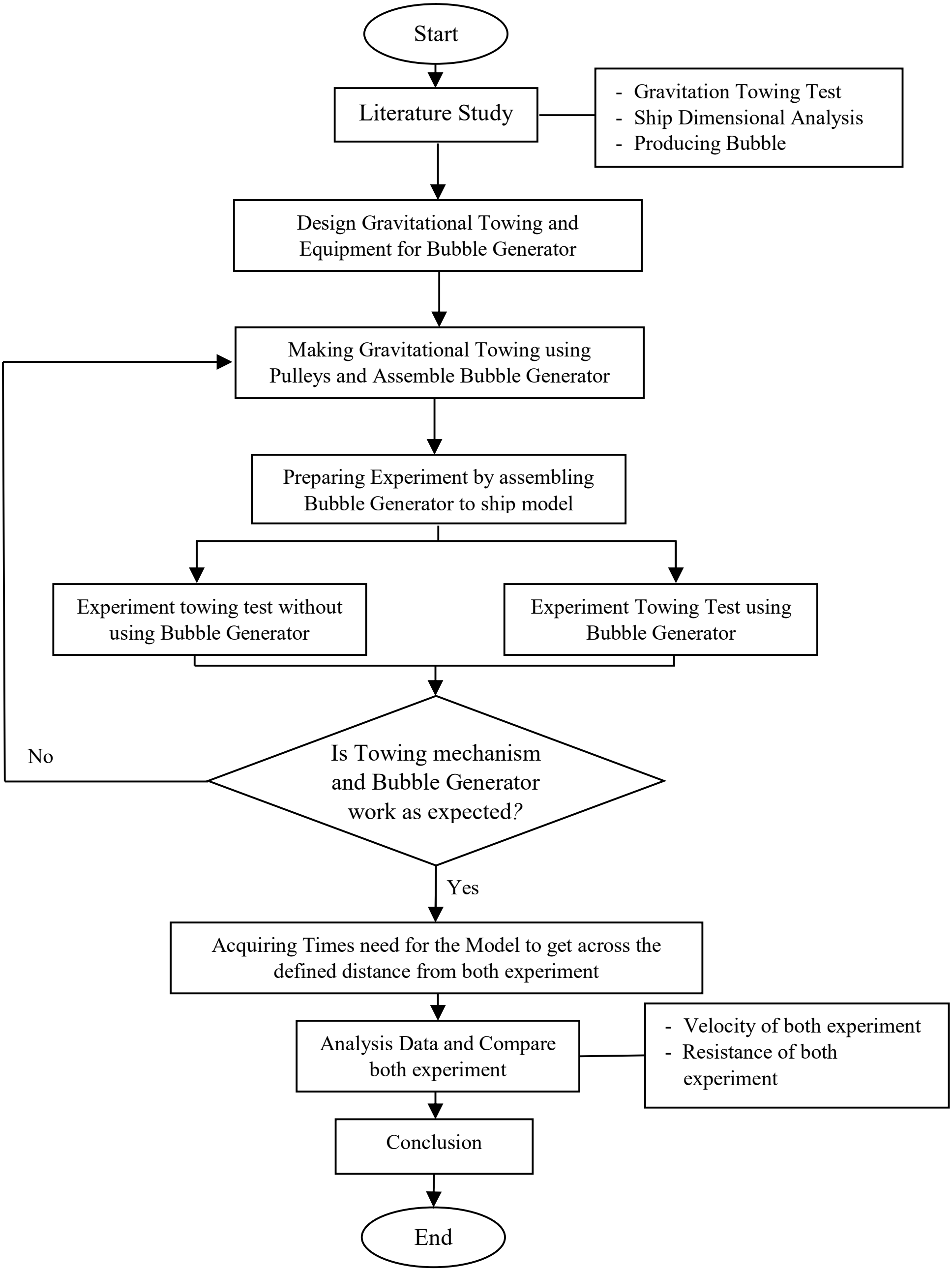


Figure 3-1. Methodology Chart

CHAPTER IV:
EXPERIMENT AND ANALYSIS

4.1 PRE-EXPERIMENT

4.1.1 Materials and Equipment

For conducting experiment, Materials and equipment are prepared and can be seen at Table 4.1, which are:

Table 4.1. Material & Equipment

	Material and Equipment	Figure
1	Ship Model	
2	Flow Channel	

Continuous from Table 4.1

3	Air Compressor	
4	Pressure Gauge	

Continuous from Table 4.1

5	Air Hose	
6	Stopwatch	
7	Weights	

Continuous from Table 4.1

8	Cord	
9	Manifold	

4.1.2 Equipment Preparation

1) Bubbles Generator

   For producing bubbles under ship model, need a design for bubble generator and component needed to make it are: Air Compressor, then intake manifold and air chamber where porous media located to produce bubble.

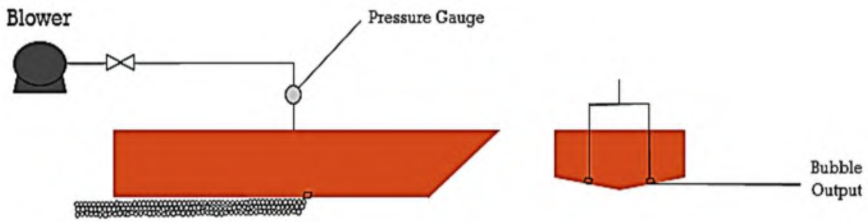


Figure 4-1. Bubble Generator

2) Gravitation Towing.
   Flow Channel Dimension with length (8.4 m), wide (1.2 m) and Deep (1 m). In this experiment, length use for experiment is 1,2 m, the limited length used for experiment is because other equipment installed inside flow channel.

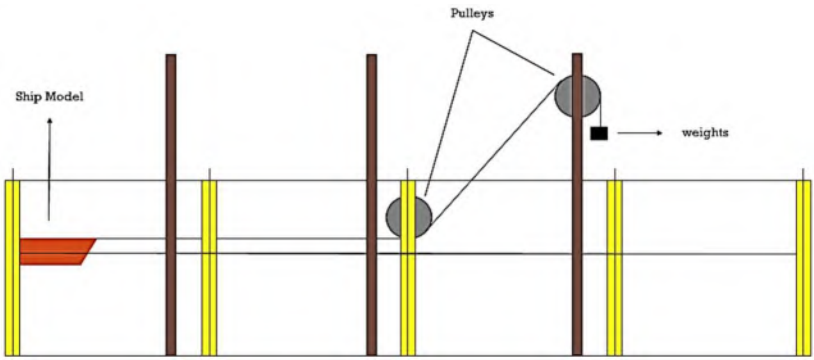


Figure 4-2. Gravitational Towing

Method for achieving resistance is using gravitational towing. This method is using weight as an accelerator to tow ship model. The weight will be varied to represent increase in the speed. By using pulleys, gravity will act as accelerator so the force will be representing as resistance need to tow the model. Figure 4-3

Figure 4-3. Pulleys

3) Installation bubble generator in ship model.
   Installing bubble generator to ship model that have been prepare by making a hole under the hull to place the bubble injector.

4.2 EXPERIMENT

4.2.1 Experiment Variable

Variables for this experiment are:

1. Experiment 1
   Independent Variable : Ship Model without using Bubbles Generator
   Control Variable : Weight for towing the ship model
   Dependent Variable : Time to cross from Point A to Point B

2. Experiment 2
   Independent Variable : Ship Model using Bubbles Generator
   Control Variable : Weight for towing the ship model
   Dependent Variable : Time to cross from Point A to Point B

4.2.2 Experiment Procedure

1) Experiment without using Air Lubrication System
   Steps for doing the experiment are:
   a) Ship model are place inside flow channel.
   b) Prepare the model to be pull with hook.
   c) Adding weight with 100 grams, 200 grams, 300 grams, 400 grams, 500 grams.
   d) Measure time need by the model need to cross 1.2 meters long flow channel after the model were pull for about 50cm - 100m

2) Experiment using Air Lubrication System
   Steps for doing the experiment are:
   a) Ship model are place inside flow channel.
   b) Prepare the model to be pull with hook.
   c) Starting the compressor and adjust pressure output at 1 bar.
   d) Adding weight with 100 grams, 200 grams, 300 grams, 400 grams, 500 grams.
   e) Measure time need by the model need to cross 1.2 meters long flow channel after the model were pull for about 50cm - 100m

4.3 EXPERIMENT RESULT

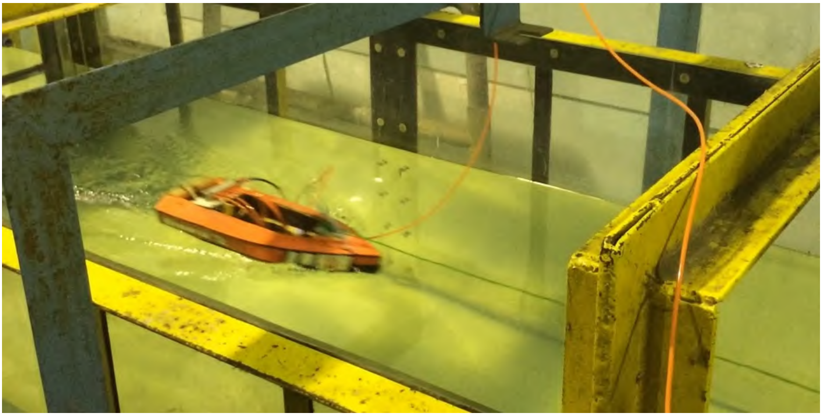


Figure 4-4. Towing Process

Figure 4-4 is showing the towing process for achieving the speed of model in different weight. When the weight is drop, the force produce by it pull the model forward. Then the model speed can be calculated from time the model need to move for 1.2 m. As shown at Figure 4-5.

Figure 4-5. Measured Time

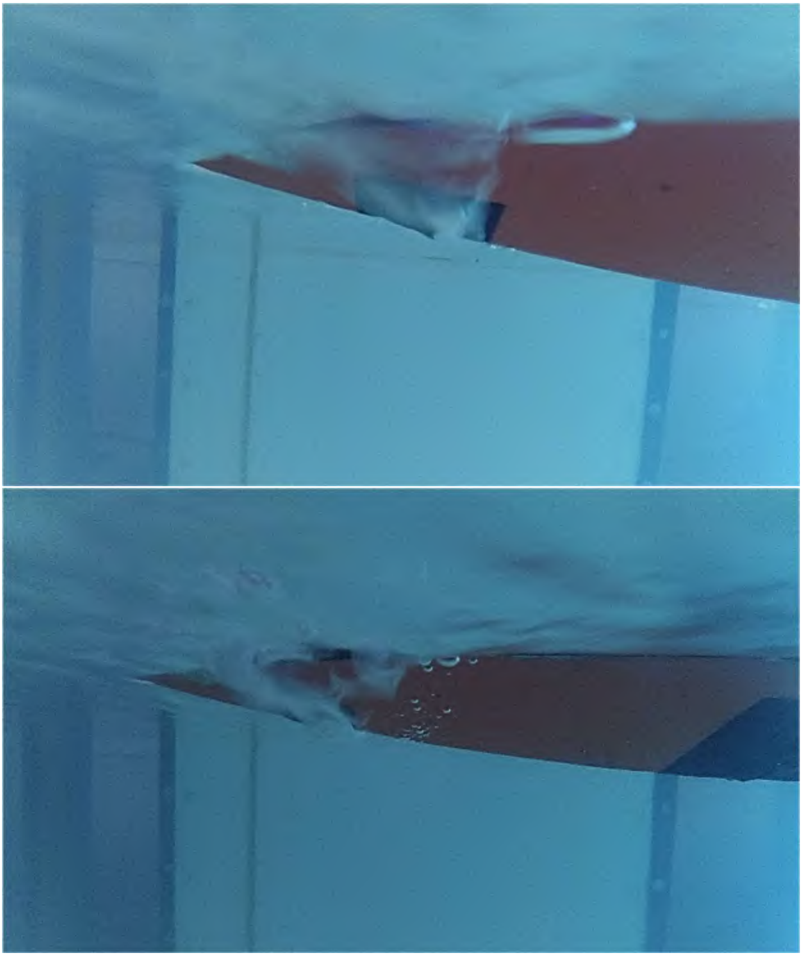


Figure 4-6. Injection at Fore of Ship

Figure 4-6 is showing the air injection when in place at the fore (forward) of the ship. The bubble injected in fore of the ship are not covering bottom of the ship. When the bubble injects by the compressor, it can be seen that the bubble did not flow to the back of the ship. The bubble goes straight to the surface.

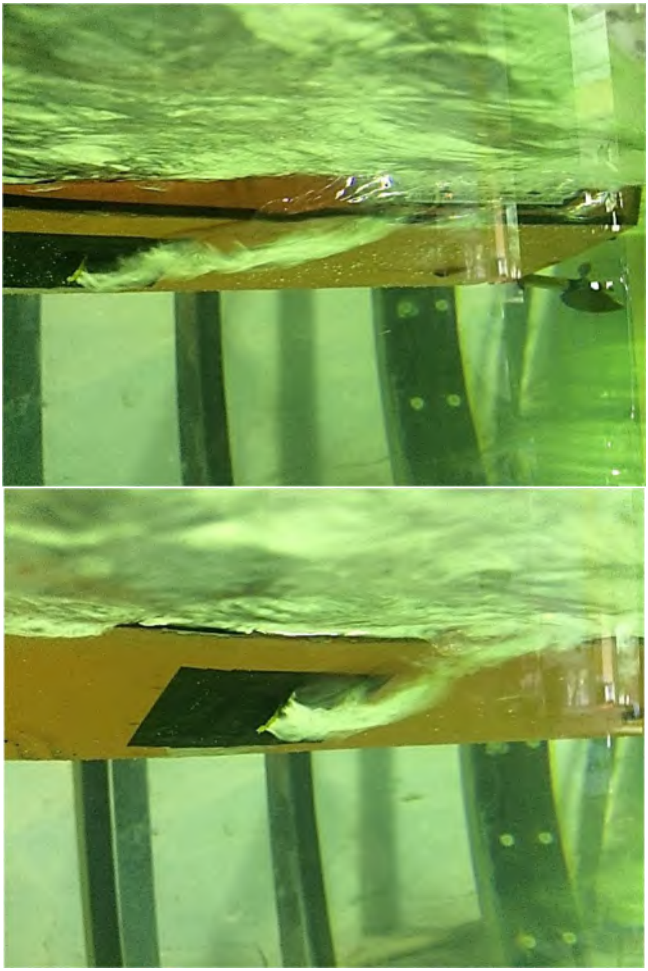


Figure 4-7. Injection at Mid Ship

Figure 4-7 is showing the air injection when in place at the mid (middle) of the ship. The bubble injected in mid of the ship are covering bottom of the ship more than the injection at fore at the ship. When the bubble injects by the compressor, it can be seen that the bubble flow to the back of the ship.

4.3.1 Experiment 1: Without Using Air Lubrication System

After measuring trap time using stopwatch, then calculate the model speed. The times used for determine model speeds are the average times from several data obtained. From the experiment result as seen at Table 4.2, can be analyses that by adding more weight the speed of model will increase. Using the data obtained, the ship resistance can be calculated.

Table 4.2. Experiment 1 Result

Mass (Kg)	Times (s)	Mean Times (s)	Velocity (m/s)	Force (N)
0.1	3.70	3.000	0.400	0.981
	2.50			
	2.80			
0.2	3.10	2.857	0.420	1.962
	2.78			
	2.69			
0.3	2.53	2.563	0.468	2.943
	2.66			
	2.50			
0.4	2.28	2.317	0.518	3.924
	2.45			
	2.22			
0.5	1.87	1.847	0.650	4.905
	1.72			
	1.95			

4.3.2 Experiment 2: Using Air Lubrication System

After measuring trap time using stopwatch, then calculate the model speed. The times used for determine model speeds are the average times from several data obtained. From the experiment result as seen at Table 4.3, can be analyses that by adding more weight the speed of model will increase. Using the data obtained, the ship resistance can be calculated.

Table 4.3. Experiment 2 Result

Mass (Kg)	Times (s)	Mean Times (s)	Velocity (m/s)	Force (N)
0.1	3.55	2.933	0.409	0.981
	2.80			
	2.45			
0.2	3.00	2.783	0.431	1.962
	2.76			
	2.59			
0.3	2.50	2.477	0.485	2.943
	2.63			
	2.30			
0.4	2.20	2.230	0.538	3.924
	2.33			
	2.16			
0.5	1.77	1.713	0.700	4.905
	1.64			
	1.73			

4.4 RESISTANCE CALCULATION

4.4.1 Calculating Ship Speed

After the model speeds are obtained, then ship speed can be calculated by using formula 2.3.3. Before calculate ship speed, first thing to do is determine the length of the ship. By doing this, the λ can calculate using formula 2.3.1. The ship is 20 m in length and the ship model is 0.75 m in length.

$$\lambda = \frac{L_s}{L_m} = \frac{20}{0.75} = 26.667$$

By doing so, the scale ratio (λ) used for calculating the ship speed. Formula 2.3.3 is used to calculate speed. For an example calculating ship speed when the model speeds is at 0.4 $^{m}/_{s}$.

$$\frac{V_s}{\sqrt{g\ L_s}} = \frac{V_m}{\sqrt{g\ L_m}}$$

$$V_s = V_m \sqrt{\lambda}$$

$$V_s = 0.4 \sqrt{26.667}$$

$$V_s = 2.066\ ^{m}/_{s}$$

Table 4.4 shown the result of ship speed *without using* Air Lubrication System from calculation:

Table 4.4. Ship Speed without Air Lubrication

Ship Speed (m/s)	Ship Speed (Knot)
2.066	1.063
2.169	1.116
2.417	1.244
2.675	1.376
3.356	1.726

Table 4.5 is showing the result of ship speed *using* Air Lubrication System from calculation.

Table 4.5. Ship Speed using Air Lubrication

Ship Speed (m/s)	Ship Speed (Knot)
2.113	1.087
2.226	1.145
2.502	1.287
2.779	1.429
3.617	1.860

4.4.2 Calculating Ship Resistance

Calculating ship speed and resistance can be done by using procedure at chapter 3.5 and experiment data from Table 4.2 and Table 4.3. For example, calculating ship resistance when the model speed is 0.4 $^m/_s$, the ship speed is 2.066 $^m/_s$, model length 0.75 m and ship length 20 m.

1. Estimate the frictional resistance of the model $(R_F)_m$ by using flat plate results at the model's Reynolds number.
   - Calculate Re Number using formula 2.3.4. where the kinematic viscosity (ν) value is 1,1883 x 10^{-6}:

$$Re = \frac{V_m L_m}{\nu}$$

$$Re = \frac{0{,}4 \, x \, 0{,}75}{1{,}1883 \text{ x } 10^{-6}}$$

$$Re = 252461{,}500$$

   - Calculate frictional resistance coefficient (C_F), using ITTC formula:

$$(C_F)_m = \frac{0{,}075}{(\log Re - 2)^2}$$

$$(C_F)_m = \frac{0{,}075}{(\log 253461{,}5 - 2)^2}$$

$$(C_F)_m = 0{,}00648$$

   - Calculate $(R_F)_{m,}$ with ρ = 1000 kg/m^3:

$$(R_F)_m = \frac{\rho\, S_m\, {V_m}^2\, (C_F)_m}{2}$$

$$(R_F)_m = \frac{1000 \text{ x } 0.1244 \text{ x } (0.4)^2 \text{ x } 0.00648}{2}$$

$$(R_F)_m = 0.078\ (N)$$

2. Compute the model residuary resistance from

$$(R_r)_m = (R_T)_m - (R_F)_m$$

$$(R_r)_m = 0.981 - 0.078$$

$$(R_r)_m = 0.903\ (N)$$

3. Since $(C_r)_s$ = $(C_r)_m$, we can find the ship residuary resistance.
   - Calculate $(C_r)_m$:

$$(C_r)_m = \frac{2\ (R_r)_m}{\rho\, S_m\, {V_m}^2}$$

$$(C_r)_m = \frac{2 \text{ x } 0.903}{1000 \text{ x } 0.15 \text{ x } (0.4)^2}$$

$$(C_r)_m = 0.07366$$

   - Calculate $(R_r)_s$:

$$(R_r)_s = \frac{(C_r)_m\ \rho\ {V_m}^2\, S_m\, \lambda^3}{2}$$

$$(R_r)_s = \frac{0.07366 \text{ x } 1000 \text{ x } \text{ x } (0.4)^2 \text{ x } 0.1244 \text{ x } 26.667^3}{2}$$

$$(R_r)_s = 17132.289\ (N)$$

4. Estimate the frictional resistance of the ship $(R_F)_s$ by using flat plate results at the ship's Reynolds number.
   - Calculate Re Number using formula 2.3.4. where the kinematic viscosity (ν) value is 1,1883 x 10^{-6}:

$$Re = \frac{V_s\, L_s}{\nu}$$

$$Re \quad \frac{2{,}066\ x\ 20}{1{,}1883 \times 10^{-6}}$$

$$Re = 34765482{,}083$$

   - Calculate frictional resistance coefficient (C_F), using ITTC formula:

$$(C_F)_s = \frac{0.075}{(\log Re \quad 2)^2}$$

$$(C_F)_s = \frac{0.075}{(\log 34765482.083 - 2)^2}$$

$$(C_F)_s = 0.00244$$

5. Calculate $(R_F)_s$, with ρ = 1025 kg/m³ and $S_s = S_m\, \lambda^2$

$$(R_F)_s = \frac{\rho\, S_s\, V_s^{\,2}\, (C_F)_s}{2}$$

$$(R_F)_s = \frac{1025 \text{ x } 88.462\text{x } (2.066)^2 \text{ x } 0.00244}{2}$$

$$(R_F)_s = 568.161 \ (N)$$

6. Compute the total ship resistance by

$$(R_T)_s = (R_F)_s + (R_r)_s$$

$$(R_T)_s = 568.161 + 17132.289$$

$$(R_T)_s = 17700.450 \ (N)$$

4.4.3 Calculation Result

a) Result of ship resistance *without* using Air Lubrication System from calculation:

Table 4.6. Model Frictional Resistance (NO ALS)

Re Model	C_F Model	$R_{F\ Model}$ (N)
252461.500	0.00648	0.078
265128.763	0.00640	0.084
295468.595	0.00623	0.102
326928.561	0.00607	0.100
410136.010	0.00575	0.181

In Table 4.6 shown the steps for calculating model frictional resistance (R_F), first calculate the Reynolds Number. The value of Reynolds Number can be used to calculate the frictional resistance coefficient (C_F). From C_F value, the model frictional resistance can be calculated.

Table 4.7 is showing the calculation result from model frictional resistance into ship residual resistance (C_R) result *without* Air Lubrication. After acquire (R_r)model, the value of residual resistance coefficient can be calculated. Because value of (Cr)model and (Cr) ship is the same, this Cr values can be used to calculate

Table 4.7. Model to Ship Resistance (NO ALS)

$R_{T\ Model}$ - $R_{F\ Model}$	$C_{R\ MODEL} = C_{R\ SHIP}$
0.903	0.07366
1.878	0.13879
2.841	0.16909
3.824	0.18593
4.724	0.14591

Table 4.8 is showing the calculation process from Ship Reynolds Number. After calculating the values of ship Frictional Resistance coefficient, the ship Resistance can be calculated.

Table 4.8. Ship Frictional Resistance (NO ALS)

Re Ship	$C_{F\ Ship}$	$R_{F\ Ship}$ (N)
34765482.083	0.00244	568.161
36509841.161	0.00242	621.826
40687820.384	0.00238	759.383
45020048.741	0.00235	915.306
56478219.991	0.00227	1391.608

Table 4.9 is showing the result of ship resistance *without* Air Lubrication System. The total resistance values get from adding the residual resistance and the frictional resistance of the ship together.

Table 4.9. Ship Resistance (NO ALS)

$R_{R\ Ship}$ (N)	$R_T=R_{F+}R_R$
17132.289	17700.450
35603.781	36225.607
53872.502	54631.885
72523.265	73438.571
89572.257	90963.865

b) Result of ship resistance *using* Air Lubrication System from calculation:

Table 4.10. Model Frictional Resistance (ALS)

Re Model	C_F Model	$R_{F\ Model}$ (N)
258199.261	0.00644	0.081
272114.191	0.00636	0.088
305808.008	0.00617	0.108
339634.304	0.00602	0.106
442053.209	0.00564	0.207

Table 4.10 shown the steps for calculating model frictional resistance (R_F) using air lubrications system, first calculate the Reynolds Number. The value of Reynolds Number can be used to calculate the frictional resistance coefficient (C_F). From C_F value, the model frictional resistance can be calculated.

Because value of (Cr)model and (Cr) ship is the same, this Cr values can be used to calculate.

Table 4.11 is showing the calculation result from model frictional resistance into ship residual resistance (C_R)

result *using* Air Lubrication. After acquire (R_r)model, the value of residual resistance coefficient can be calculated.

Table 4.11. Ship to Model Resistance (ALS)

$R_{T\ Model}$ - $R_{F\ Model}$	$C_{R\ MODEL} = C_{R\ SHIP}$
0.900	0.07018
1.874	0.13148
2.835	0.15750
3.818	0.17201
4.698	0.12492

Table 4.12 is showing the calculation process from Ship Reynolds Number. After calculating the values of ship Frictional Resistance coefficient, the ship Resistance can be calculated.

Table 4.12. Ship Frictional Resistance (ALS)

Re Ship	$C_{F\ Ship}$	$R_{F\ Ship}$ (N)
35555606.676	0.00243	592.192
37471777.096	0.00241	652.372
42111620.289	0.00237	809.144
46769706.838	0.00233	982.072
60873412.208	0.00224	1598.487

Table 4.13. Ship Resistance (ALS)

$R_{R\ Ship}$ (N)	$R_T = R_F + R_R$
17073.480	17665.673
35529.353	36181.725
53752.406	54561.550
72407.779	73389.851
89086.902	90685.389

Table 4.13 is showing the result of ship resistance *without* Air Lubrication System. The total resistance values get from adding the residual resistance and the frictional resistance of the ship together.

c) Result of calculating ship resistance:

Table 4.14 Calculation Result without Air Lubrication

No	Without ALS			
	Model		Ship	
	Speed (Knot)	Resistance (N)	Speed (Knot)	Resistance (N)
1	0.206	0.981	1.063	17700.450
2	0.216	1.962	1.116	36225.607
3	0.241	2.943	1.244	54631.885
4	0.266	3.924	1.376	73438.571
5	0.334	4.905	1.726	90963.865

Table 4.15 Calculation Result using Air Lubrication

No	With ALS			
	Model		Ship	
	Speed (Knot)	Resistance (N)	Speed (Knot)	Resistance (N)
1	0.210	0.981	1.087	17665.673
2	0.222	1.962	1.145	36181.725
3	0.249	2.943	1.287	54561.550
4	0.277	3.924	1.429	73389.851
5	0.360	4.905	1.860	90685.389

Table 4.14 and Table 4.15 showed the calculation result of speed and resistance for both experiment *using* Air Lubrication System and Experiment *without using* Air Lubrication System.

4.5 DATA ANALYSIS

4.5.1 Speed Different Analysis

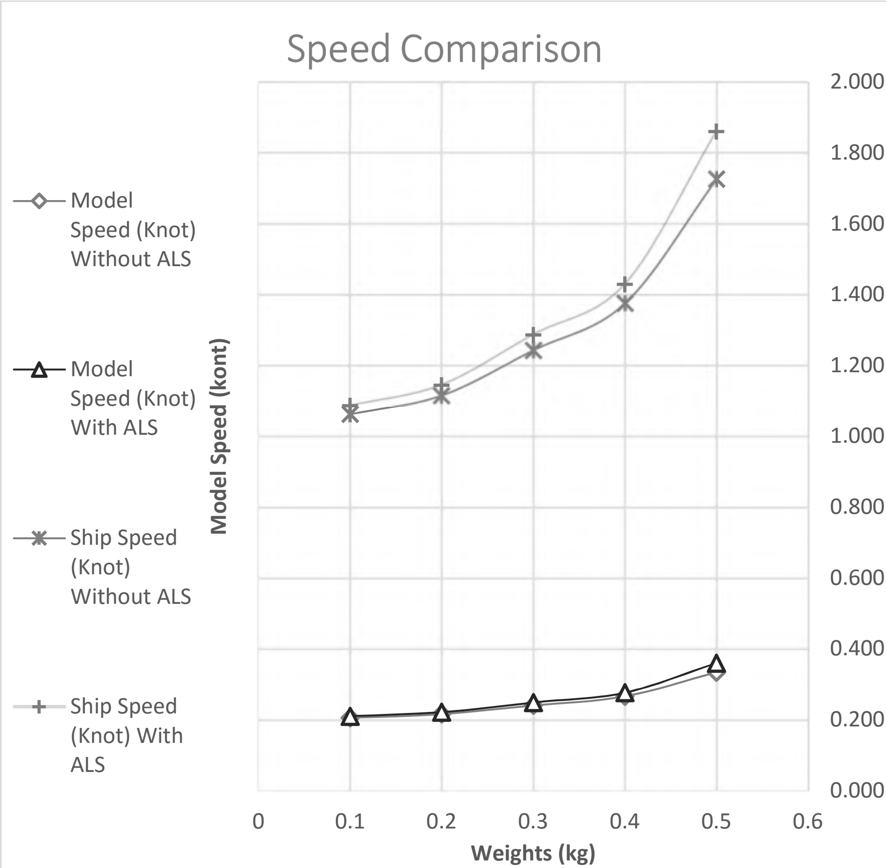


Figure 4-8. Speed Comparison

Data at Table 4.4 and Table 4.5 are representing the model speed and ship speed, that the speed at both model and ship are compare with the different by using air lubrication and not using air lubrication. From the comparison, the different of speed when using Air Lubrication is slightly increase at same resistance or weight given. This result can be seen at Figure 4-8 where the comparison of speed and weight shown the speed using air lubrication increase. At the same weight, the speed increase in average 4% when it uses air lubrication system. Where at weight given is 0.4 kg the speed ship speed without using Air lubrication is 1.376 m/s, and the ship speed using air lubrication is 1.429 m/s.

4.5.2 Ship Resistance Analysis

Figure 4-9 above is representing the ships speed and resistance correlation. As seen in the graph, when speed increase, the resistances is also increasing and with the uses of air lubrication the speed increase at same resistance.

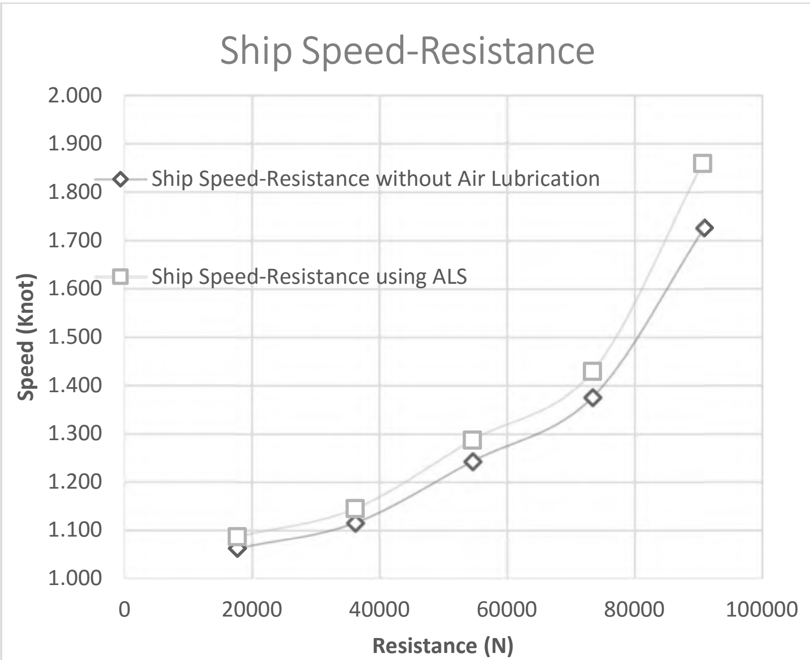


Figure 4-9. Ship Speed-Resistance

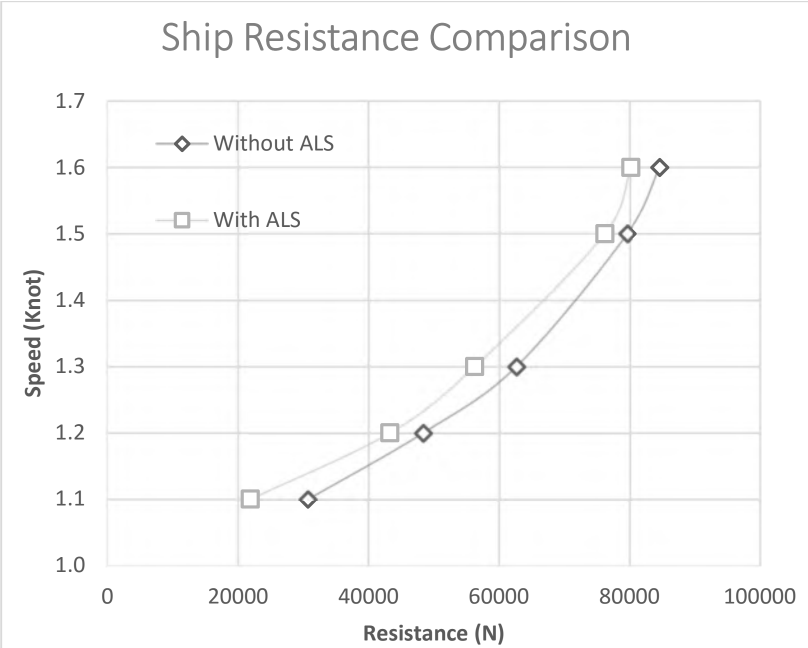
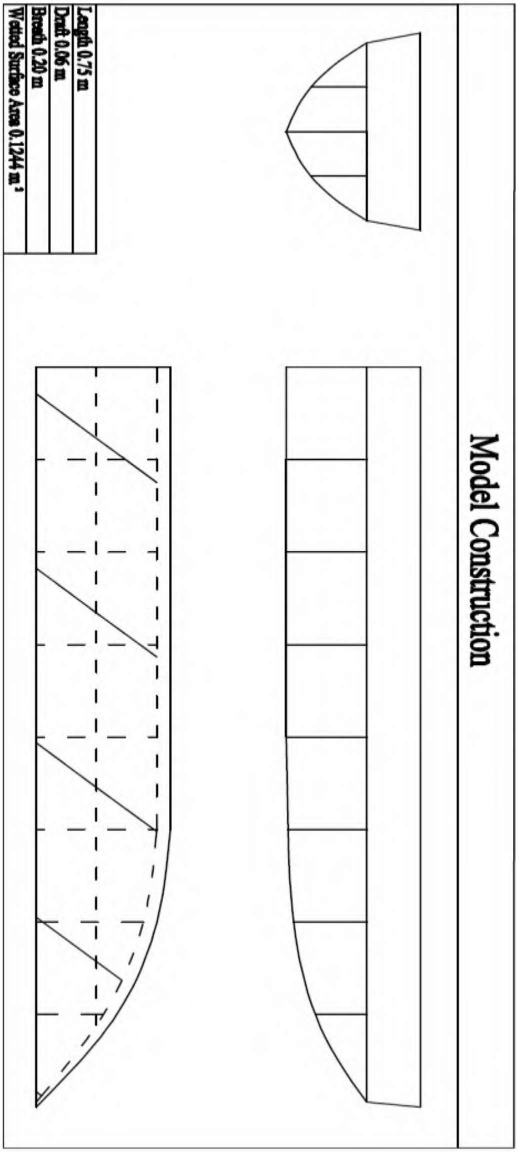


Figure 4-10. Ship Resistance

Figure 4-10 is showing the different resistance value at same ship speed. From the graph, the resistances were decline in average of 11.8%. For example, at speed 1.2 m/s, the resistance of a ship without using air lubrication is 48355 N and when ship using air lubrication the resistance is 43277 N.

ATTACHMENT



Model Construction
Length 0.75 m
Draft 0.06 m
Breath 0.20 m
Wetted Surface Area 0.1244 m²

CHAPTER V:
CONCLUSIONS AND SUGGESTIONS

5.1 CONCLUSIONS

After conduction experiment and analysis, using air lubrication system to a ship model to reduce frictional resistance. Can be concluded that:

1. There were some different average speeds comparing the result from experiment model without using air lubrication and using lubrication at the same amount of weight given for towed the ship. With weight of 0.4 kg, average speed for ship model without using air lubrication is 0.518 m/s. For ship model using air lubrication the average speed is 0.538 m/s.
2. From calculation results, can be obtained resistance value at a speed of 1.3 knots, ship resistance without the use of ALS is 62650,635 N, while the ship resistance when using ALS is 56272,822 N.
3. Comparing the experiment result at same resistance, the speed for ship using air lubrication were increase in average 4%.
4. Comparing the experiment result at same speed, resistance value for ship using air lubrication system were shown decrease in average 11.8%

5.2 SUGGESTIONS

This study result is not perfect, there still room for improvement for better result can be obtain in the future. For the next research suggestions are:

1. To improve future experiment
   - Using longer distance to get more accurate result of times and improve the gravitational towing so the speed of the model when towed can be more constant
   - Using other method for producing bubble
   - Using a flat bottom model to get a better surface area to cover the bottom of model
2. Doing more research about using different pressure when inject the air to produce bubbles.

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AUTHOR BIOGRAPHY

Author was born in Duri, Riau on 01 January 1994 and last child after 2 sisters. Author has undergone formal education from Cendana Kindergarten, Cendana Mandau Elementary School, Cendana Mandau Junior High School, Cendana Mandau Senior High School and currently study at Institut Teknologi Sepuluh Nopember at Department of Marine Engineering, in class 2012. When author studying at ITS, the author had been active in academic and non-academic activities. Among author achievements are 3rd Place Solo Tenor Drum at Jember International Marching Competition 2015 and 1st Place Solo Tenor Drum at Delta Marching Open Festival Indonesia 2016. The author had attended training ship papers and training as well as seminars that support the skills the writer as a marine engineer. The author has been carried out On Job Training at PT. Galangan Mercusuar Batam and PT. Alstom (GE) Power Energy System Indonesia.

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